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Title

Determinants of bird conservation action implementation and associated population trends of threatened species

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Statement of authorship

DL, TB, SB, MH, JL, AU designed the study. SB provided the data. MK performed modeling work and analyzed output data. DL wrote the first draft of the manuscript and all authors contributed substantially to revisions.

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Abstract

Conservation actions, such as habitat protection, attempt to halt the loss of threatened species and help their populations to recover. Thus far, research has examined the efficiency and the effectiveness of actions individually, yet~~,~~ conservation actions generally occur simultaneously so the full suite of implemented conservation actions should be ~~considered~~assessed. We used the conservation actions associated with the threatened birds of the world (IUCN Red List) to assess which biological ~~factors~~ (related to taxonomy and ecology) and anthropogenic factors (related to geo-economics and population trends) are associated with the implementation of different classes of conservation actions. We also assessed which conservation actions are associated with increasing population trends. Threat category, taxonomic order, and geo-economic variables were the strongest predictors of implemented ~~which~~ conservation actions ~~were implemented~~. Species with invasive alien species control/eradication, *ex-situ* conservation, international legislation, reintroduction, or education and awareness-raising were more likely to have increasing populations. I'd add a sentence in listing the less effective actions. These results illustrate the importance of developing a predictive science of conservation actions and the relative efficiencies of each class of implemented conservation action for threatened and near-threatened birds around the world.

Introduction

Due to human activities, the rate of species extinction is higher now than at any other time in the past 65 million years (Barnosky et al 2011, Pimm et al 2014). Conservation efforts aim to slow ~~down~~, stop, and reverse threats to species and thus the current loss of biodiversity. However, the extinction risk to species continues to rise (CBD 2014~~,~~). This does not mean conservation efforts have failed. Indeed, conservation efforts have circumvented at least 20% of projected increases in aggregate extinction risk to birds and mammals over the last four decades, as measured by changes in the IUCN Red List of Threatened Species (hereafter, "Red List") (Hoffmann et al 2010). For ungulates, increases in aggregate extinction risk since 1996 would have been eight times greater in the absence of conservation action (Hoffmann et al 2015).

Targeted actions to recover birds have been particularly successful. For example, between 1994 and 2004, conservation efforts likely prevented at least 16 bird species from going extinct (Butchart et al 2006, Rodrigues 2006). The implementation of conservation actions for threatened species is critical if we are to support the recovery of currently threatened species, as agreed in Aichi Target 12 of the 2010–2020 Strategic Plan for Biodiversity (https://www.cbd.int/sp/targets/) and prevent more species from declining and going extinct.

Research on the suite of parameters that affect extinction risk for threatened species, including biological and geo-economic factors and threats, has made great progress toward predicting extinction risk (Bland et al 2014, Cardillo et al 2006, 2008, Davidson et al 2009, Davies et al 2006, Fisher and Owens 2004, Mace 2004, Owens and Bennett 2000, Purvis et al 2000). While these studies have been remarkably informative about the extinction risk and threats facing species, it is only through the implementation of conservation actions that we have a chance to improve the status of threatened species. Thus, just as there currently is a predictive science of extinction risk, there is a need for a predictive science of conservation actions, which would illuminate how, why, and where conservation actions are best implemented for threatened species and assess their efficiency.

Such a predictive science of conservation actions has not been completely overlooked. Hayward (2011) used a subsample of 144 threatened mammals from the Red List that improved or declined in status between 2004 and 2008 assessments to assess the link between threats, conservation actions, and population trends. Brooks et al (2009) focused on the suite of conservation actions implemented in tropical rainforests to examine their effectiveness. Chapman (2014) surveyed experts about conservation actions as to whether they thought the actions were successful. Finally and most comprehensively, Williams et al (2012) conducted a literature review that assessed the efficiencies of each of the IUCN conservation action categories for birds. Building off of these attempts to assess the efficiency and effectiveness of implemented conservation actions, we assess the biological and geo-economic parameters that influence conservation action implementation and are associated with increasing population trends, using data for birds from the Red List.

Here, we assess which factors predict implementation of conservation actions, and examine which actions are associated with different directions of population trends for threatened and Near Threatened bird species (i.e. in the categories of Critically Endangered, Endangered or Vulnerable).

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Material and methods

We examined the conservation actions underway for species assessed by BirdLife International as threatened (i.e., Critically Endangered, Endangered or Vulnerable) or Near Threatened on the Red List (BirdLife International IUCN red List for birds 2014 http://www.birdlife.org on May 27 2014). We excluded those Critically Endangered species tagged as Possibly Extinct (PE) because most such species require targeted searches to rediscover any surviving individuals before the most appropriate conservation actions can be determined.

Birds are an excellent study group to investigate such questions, because all birds have been comprehensively assessed against the Red List Categories and Criteria (IUCN 2012), revealing 1,373 species to be threatened and 959 to be Near Threatened; i.e., 22% of the world's 10,425 bird species are considered of elevated conservation concern (BirdLife International 2014). Further, 145 species are assessed as recently Extinct, Extinct in the Wild, or Critically Endangered (Possibly Extinct) (1% of all bird species) and only 62 are Data Deficient (0.5% of all bird species). Moreover, bird populations occur in most habitats and all countries worldwide, they are easily identifiable, practical to monitor and research, and there are large networks of people studying birds, compiling information about them and implementing conservation actions for them (Brooks et al 2008).

We used data on conservation actions underway as documented in the Species Information Service, the database co-managed by IUCN and BirdLife International, which underpins the Red List. The fields for conservation actions underway largely represent a subset of the actions in the classification scheme developed by Salafsky et al (2008), and relate to a subset of those actions for which meaningful data can be compiled for the majority of species on the Red List (see Table 1). Conservation actions included in the database represent those that are ongoing or took place within the last decade. One conservation action we excluded was the identification of 'important sites' for species. Because nearly all (>95%) of threatened and Near Threatened bird species have Important Bird and Biodiversity Areas (IBAs) identified for them (BirdLife International 2014b), this parameter would have little explanatory power in our analysis. We examined both biological and anthropogenic factors as independent predictor variables of conservation action implementation (see Table 1). We also included monitoring which is not technically a conservation action according to Salafsky et al (2008) but is instead a research need, yet tends to be a critical component in terms of assessing population trends as related to conservation actions. All biological data were extracted from the Species Information Service in July 2012 (http://www.birdlife.org/datazone/species).

For the habitat type used by each species, we considered only the broad 'level 1' classes (http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3) coded as being of major importance during the breeding season. To simplify the analyses, we summed the four marine habitat subcategories, neritic, intertidal, marine coastal and oceanic, to create a more general “marine” category (which included 107 species), and pooled the categories for caves and rocky areas, introduced vegetation and artificial terrestrial/aquatic habitats, other habitats, and unknown habitats into a class we termed “other” (which included 142 species). Species that inhabit multiple geographic realms were scored in a “multiple” category, we scored species in multiple landmass types in a “multiple” category as well.

Geo-economic factors, which describe the economic development of the places where species live, can be an important determinant of conservation implementation. To calculate the per capita area-weighted Gross Domestic Product (GDP) for a species, we averaged the GDP for all countries in which each species occurs relative to the portion of its range within each country (Rodrigues et al 2014). The GDP is calculated as per capita in 1990 international Geary-Khamis dollars. GDP data are from the World Economic Outlook by the International Monitary Fund (2014 dataset): http://www.imf.org/external/data.htm. One hundred and eighty-eight countries belong to the IMF. For the few that do not belong to it, we used estimates of GDP from the CIA Factbook (accessed 21 Feb 2015; see SOM for a list of countries):

https://www.cia.gov/library/publications/the-world-factbook/fields/2004.html.

Binomial regression models were fit to explain the presence of conservation actions for 2,177 bird species. Missing data, among 4 variables with between 0.05%

and 5.9% missing (see SOM for details of missing data), were singly imputed (Figure 1).

Best models were selected using a combination of the Akaike Information Criterion (AIC) and an assessment of the generalized variance inflation factor to ensure low collinearity among predictors. Collinearity among predictors was judged acceptable when the generalized variance inflation factor was below $\sqrt{3}$ (Zuur et al 2010). If the generalized inflation factor was > $\sqrt{3}$, that model was not considered valid. After a final model was selected, Pearson residuals were binned and examined to ensure no patterns emerged that would suggest an important predictor was left out of the model. Residuals were plotted against all predictor variables, both those included and excluded from the model, to ensure important predictors had not been removed. Model averaging was conducted on the best models so that the cumulative Akaike weight ≥ 0.95 (Johnson and Omland 2004) for each of the nine conservation actions, resulting in one average final model for each conservation action. The best models used for averaging are reported (Supplemental Online Material Table 1) along with the averaged parameter estimate, unconditional standard error, and confidence intervals (Supplemental Online Material Table 2). To determine the importance of variables we calculated the 90% (estimate ± 1.64SE) and 95% (estimate ± 1.96SE) confidence intervals around the model averaged parameter estimates (Kittle et al., 2008; Mazerolle 2004). If the confidence interval does not contain 0 we can conclude that the parameter has an effect on the dependent variable (i.e. the estimate is different from 0).

Using linear regression, the relationship between predictor variables and the number of conservation actions was analyzed.

Finally, a binomial regression model was fitted (using AIC and the generalized variance inflation factor as detailed above) to explore which conservation actions were associated with an increasing versus decreasing population trend for threatened and Near Threatened bird species. Population trends are based on ongoing trend data over the last several years. Coefficients for binomial regression were interpreted as the odds ratio using the antilog of the raw coefficients. Numerical results are reported as mean ± SEM. All tests were conducted using R statistical software, ver. 3.0.2, R Core Team 2014.

Results

Number and Class of Implemented Conservation Actions

In total, 5,424 conservation actions are documented as being implemented for the 2,177 threatened and Near Threatened bird species on the Red List, with a mean of 2.55 ± 0.028 conservation actions per species. The most frequent conservation action implemented was for a protected area to cover a population of the species (74% of species). International trade regulations and action plans exist for 23% and 18% of species, respectively. Other conservation actions were implemented for < 10% of species. Predictive models for the conservation actions, international trade regulations, international legislation, invasive species control, and action plans, all had relatively high weighted-explained deviance, 0.68, 0.59, 0.55 and 0.54, respectively. Predictive models for other conservation actions, Ex Situ conservation, monitoring, reintroduction, education and population protection didn't explain the deviance as well, 0.38, 0.35, 0.29, 0.21, 0.2, respectively.

Red List category was the most important predictor for conservation action implementation. More severely threatened species were more likely to be targeted by more conservation actions, with Critically Endangered and Endangered species having significantly more conservation actions than Vulnerable and Near Threatened species ($F_{3,2173} = 45.56$, $P < 0.001$).

Species that live in Europe or multiple regions had the most conservation actions implemented, while species in West and Central Asia, North Africa, and Antarctica had the fewest ($F_{13,2163} = 21.69$, $P < 0.001$). In addition, species that breed in more countries have more conservation actions implemented ($F_{1,2175} = 240.4$, $P < 0.001$). For every 1% increase in the ~~amount~~ area of a species range within G20 or OECD countries, the number of conservation actions increased by 0.00196 and 0.0093, respectively ($F_{1,2175} = 9.54$, $P = 0.002$; $F_{1,2175} = 148.8$, $P < 0.001$). As the area-weighted GDP of species increased, so did the likelihood that the species would have conservation actions in place ($F_{1,2175} = 81.51$, $P < 0.001$).

Species' biology was also associated with the implementation of conservation actions. Species with longer generation times were more likely to have more conservation actions. For every year increase in generation length, the number of conservation actions implemented increased by 0.13 ($F_{1,2175} = 482.6$, $P < 0.001$). Species that inhabit marine and inland wetland had more conservation actions in place than species in other habitats ($F_{7,2169} = 20.28$, $P < 0.001$). More specifically, species in these habitats tended to have more monitoring, protected areas, invasive alien species control/eradication, *ex-situ* conservation, and international legislation. The type of landmass where a species occurred was an important predictor variable for all implemented conservation actions except education and awareness-raising, reintroduction, and *ex situ* conservation, with more actions implemented for species inhabiting oceanic islands ($F_{3,48} = 9.22$, $P < 0.001$).

Taxonomic order was an important factor in all ten best models for education and awareness-raising, action plans, *ex situ* conservation, international legislation, and trade control. The taxonomic orders Anseriformes (ducks, geese, and swans), Falconiformes (raptors), Gaviiformes (divers/loons), Phoenicopteriformes (flamingoes), and Psittaciformes (parrots) had the highest numbers of conservation actions while Caprimulgiformes (nightjars), Columbiformes (pigeons), Cuculiformes (cuckoos), Passeriformes (perching birds), and Piciformes (woodpeckers) had the fewest ($F_{23,2153} = 21.68$, $P < 0.001$).

Conservation Actions and Population Trends

Among threatened and Near Threatened bird species, 83% have decreasing population trends, 3% increasing, 11% stable, and 2% have unknown population trends (BirdLife International 2014). Population trend was a predictor variable in 58% of the models. Specifically, it was a predictor in all ten best models for *ex situ* conservation, invasive alien species control/eradication, reintroduction, and international trade controls. Species with increasing populations had more conservation actions in place (4.01 ± .185) than those with decreasing (2.51 ± 0.03), stable (2.47 ± 0.09) or unknown population trends (0.98 ± 0.14) ($F_{3,2173} = 34.31$, $P <$

0.001). The best generalized binomial regression model that explained an increasing or decreasing population trend based on the conservation actions in place included education and awareness-raising, international legislation, reintroduction, *ex-situ* conservation, and invasive alien species control/eradication (Table 2). Species with these conservation actions showed increased odds of having a positive population trend of 2.16, 2.62, 2.82, 3.09, and 10.63 respectively (Figure 2).

Discussion

These results depict both the biological and anthropogenic environment in which conservation actions are most likely to be implemented and are most likely to be effective. More severely threatened species received more types of conservation actions, presumably because the conservation of more severely threatened species is seen as more urgent, and/or because more threatened species face a wider range of threats. Species with increasing population trends had 1.6 times more conservation actions in place than those with stable or decreasing populations, suggesting that implementation of multiple conservation actions may be more effective in reducing extinction risk. In particular, the implementation of invasive alien species control/eradication, *ex-situ* conservation, international legislation, reintroduction, and education and awareness-raising were most frequently associated with positive population trends. Knowledge of the circumstances in which conservation actions are implemented as well as which ones are most successful, such as we describe here, could tremendously benefit the future of species conservation with implications for future resource allocation for conservation actions as well as assessments of the potential success of different types of actions.

Biological factors important in predictive models of biodiversity threats, such as generation length, clutch size, taxonomic group, and habitat type, were also important in all of the best predictive models of conservation action implementation. In particular, generation length was an important predictor for five of the nine conservation action types assessed and is an important predictor in threat models (Owens and Bennett 2000, Fisher and Owens 2004). Many of the biological factors in the models are correlated with taxonomy, and closely related species within taxonomic groups are generally susceptible to similar threats (Gaston and Blackburn 1995, Mace 2004, Owens and Bennett 2000); consequently, they tend to receive similar conservation actions.

Taxonomic order was an important factor associated with education and awareness-raising, action plans, *ex situ* conservation, international legislation, and trade control, suggesting that these five classes of conservation action tend to be applied in a taxonomically selective way. Species in taxonomic groups that are particularly threatened by over-exploitation, such as Anseriformes, which are threatened by hunting (Green 1996), Psittaciformes, which are threatened by trapping for the pet industry (Collar and Juniper 1992, Wright et al 2001) and Falconiformes, some of which are threatened by trapping for falconry (Butchart et al 2005), receive a disproportionate number of conservation actions compared with species in other orders. Species in these orders tend to be particularly palatable, colorful, carnivorous, or otherwise charismatic, explaining both their attractiveness for harvest as well as conservation attention (Leader-Williams & Dublin 2000).

Whether a species lives on an oceanic island, continental island, or continent was an important predictor for six of the nine conservation actions. Being on an oceanic island was a strong predictor of the existence of action plans, international legislation, international trade regulations, and invasive species control/eradication implementation, while species on continents had more monitoring and protected areas. Invasive species have been a leading cause of extinction for native species on islands (Clavero and Garcia-Berthou 2004). However, eradicating invasive species is an increasingly applied and successful conservation tool (Veitch, Clout, and Towns 2011). Our finding that populations of threatened and Near Threatened species are ten times more likely to be increasing when invasive species control/eradication is implemented is a strong signal that this conservation action has a positive impact on such species. With ongoing declines in oceanic seabird populations, international legislation has been strengthened to reduce threats to these species, as they typically cross national borders and often use areas beyond national jurisdiction while foraging or migrating (Croxall et al 2012, Wolf et al 2006). Given the high rates of endemism and endangerment of species on oceanic islands, more protected areas (and their effective management) could help conserve their populations (Kier et al 2009).

The implementation of conservation actions requires adequate resources (McCarthy et al. 2012), which explains the importance of geo-economic factors as predictors of the implementation of many conservation actions. Geo-economic factors were present in all of the ten best models, except for education and awareness-raising, and species in more economically developed countries are more likely to receive conservation actions. This appears to be consistent with the Kuznets curve, which predicts that there is an hump-shaped relationship between wealth and environmental quality (Mills and Waite 2009), whereby improving population trends for threatened and Near Threatened species coincided with wealthy countries. However, among poor countries, increases in wealth can lead to increased threats, which can create a complex relationship between a country's financial resources and the conservation of biodiversity (Mills and Waite 2009). Another complication with economic predictive variables is that finances often flow across international borders, which can lead to the transfer of funds for conservation efforts as well as the transfer of threats, such as logging and the harvesting of species (Lenzen et al. 2012, Weinzettel et al 2013). However, some of the richest countries have shown poor results with regard to species recovery, while many of the best successes have come from countries with small per capita GDPs (Rodrigues et al 2014), illustrating that finances alone cannot explain the implementation or efficiency of conservation actions.

Reintroduction, *ex-situ*, invasive alien species control/eradication, education and awareness-raising efforts, and international legislation are all significantly associated with increasing population trends among species of conservation concern. Action plans, monitoring, protected areas, and international trade controls are associated as well, but not significantly. The reasons for these differences are not clear. Certainly, reintroduction and invasive alien species control/eradication are highly targeted actions, which can often yield dramatic positive results. Conversely, action plans and monitoring are preconditions to other conservation actions and alone are insufficient to ensure population increases (furthermore, the existence of an action plan does not necessarily imply that it is being implemented adequately, or at all). Unfortunately, trade controls can often be ineffective, with illegal trade being a widespread issue for utilized species (Magnin 1991). In addition, some conservation actions might have interactive effects that increase opportunities for population recovery. For example, invasive species eradications coupled with reintroductions might increase the likelihood of population recovery more than one of these conservation actions alone.

A predictive science of conservation action implementation and effectiveness should increase the future success of conservation efforts. While our models accounted for many of the biological and anthropogenic factors thought to be associated with threats to species and hence potentially with conservation action implementation, additional factors are likely to play a role. Climate change is an important variable that we did not account for; however, all of the conservation actions that we assessed can be implemented in a "climate smart" manner and remain relevant in the presence of climate change (McClanahan et al 2008, Stein et al 2014). Future efforts should also look at the relationship between particular threats and the implementation of conservation actions, specifically to measure the alignment between them and to use that as a predictor for positive population trends. Future research should investigate similar questions in other taxa and refine our results to pinpoint the correlates of successful conservation actions and help improve the overall effectiveness of conservation action for species of conservation concern.

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Tables

Table 1. Types of conservation actions underway that were used in the analysis, plus the variables used to predict conservation action implementation with citations from papers that found these variables to be important in predicting extinction risk.

Conservation Actions	**Definition**	**IUCN classification scheme**
Action Plan	An action/recovery plan exists for the species	Research Needed 2 Conservation Planning
Monitoring	The species is subject to a systematic monitoring scheme	Research Needed 3 Monitoring
Protected Area	The species occurs in at least one protected area	
Invasive Species Control/Eradication	Invasive alien species which impact the species are being (or have been) eradicated, controlled or prevented from spreading	2.2 Invasive/problematic species control
Reintroduction	The species is being (or has been successfully) reintroduced or introduced benignly for conservation purposes	3.3 Species re-introduction
Ex Situ	The species is subject to ex-situ conservation	3.4 Ex-situ conservation
Education /awareness-raising	The species is subject to ongoing (or recent) education and awareness programmes	4 Education & awareness
International Legislation	Species is listed in international legislation (e.g. on Appendicies of CITES and/or CMS and/or its Agreements and Instruments (ACAP, AEWA etc)	5 Law & policy
International Trade Management	Species is subject to international management/trade controls	6 Livelihood, economic & other incentives

Predictor Variables	**Citations**
Direction of population Trend	
IUCN Red List Category	
Taxonomic Order	Mace 2004
Body Mass	Gaston and Blackburn 1995; Owens and Bennett 2000; Fisher and Owens 2004;
Clutch Size	Fisher and Owens 2004
Generation Length	Owens and Bennett 2000; Fisher and Owens 2004;
Landmass Type	Davies et al 2006
Habitat Type	Owens and Bennett 2000
Biogeographic Region	Purvis et al 2000; Cooper et al 2008
Number of Countries in Species Range	
Size of Breeding Range	Fisher and Owens 2004; Owens and Bennett 2000
Proportion of Range in G20 countries	Chapron et al 2010

Proportion of Range in OECD countries	Christie et al 2006
GDP of Countries Within Species Range	McKinney 2002; Davies et al 2006

Table 2. AICc models for conservation actions associated with increasing population trends of Threatened and Near Threatened species.

Population Trend	logL	k	AICc	ΔAICc	weight
Education + Int Legislation + Reintroduction + *Ex Situ* + Invasive Control	-250.90	5	513.85	0.00	0.35
Education + Int Legislation + Reintroduction + *Ex Situ* + Invasive Control + Action Plan	-250.05	6	514.17	0.32	0.30
Education + Int Legislation + Reintroduction + *Ex Situ* + Invasive Control + Action Plan + Protected Areas	-249.39	7	514.85	1.00	0.21
Education + Int Legislation + Reintroduction + *Ex Situ* + Invasive Control + Action Plan + Protected Areas + Int Trade	-249.09	8	516.27	2.42	0.10
Education + Int Legislation + Reintroduction + *Ex Situ* + Invasive Control + Action Plan + Protected Areas + Int Trade + Monitoring	-249.00	9	518.13	4.27	0.04

Figures

Figure 1. Schematic of the data flow.

Figure 2. Estimate and 95% confidence interval of odds ratio of implemented conservation actions associated with increasing population trends of threatened and Near Threatened bird species.